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Evaluating a Swedish Airborne Combat Capability using Computer Supported Morphological Analysis

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Abstract

General morphological analysis (MA) is a method for structuring and analysing the total set of relationships contained in multi-dimensional, non-quantifiable problem complexes, and for synthesising solution spaces. During the past ten years, MA has been extended, computerised and applied by FOI for scenario development, long-term strategy management and organisational structuring. This article outlines the fundamentals of the morphological approach and describes its use in a study carried out by the Swedish Army Command concerning the development of an airborne combat capability. The study was to evaluate how such a capability can enhance armed forces' operations in a fifteen-year perspective. Morphological analysis (MA) was utilised for the initial structuring and analysis of the relationships between the variables involved, among these tactical, organisational, economic, and command and control.

1. BACKGROUND

Sweden does not presently have airborne combat units with close air support (CAS) capability. However, one ground combat battalion, which is intended to be part of a larger "airborne capability", was established in 2002 and has begun training. Since the airborne concept will take time to develop, it should be built up in several steps, starting with a ground combat unit.

Sweden is also in the process of renewing its helicopter fleet. New transport helicopters have been ordered, but a decision concerning combat helicopters remains to be taken. In this context, the Swedish Army Command has carried out a study of "Airborne Capability" based on the following task description:

"Analyse the concept airborne capability and investigate to what degree such a capability can enhance operational and tactical levels of armed forces' operations. Describe an airborne unit consisting of a ground combat unit, a transport helicopter unit and a combat helicopter unit as one organized unit or, alternatively, as separately organized units. Investigate both the potentials and possible limitations involved in different alternatives -- and recommend one."

The study was to include:

- Tactical, organizational and economical objectives for the ground combat unit,
- Recommendations for how C^2 at operational and tactical levels for the airborne unit should be organised,
- A plan and time table for how the ground combat unit, consisting of conscripts, could be built up and trained and
- A suggestion for how the airborne unit should train *before* helicopters are available or operational (transport helicopters should be available 2006-07, and the combat helicopters sometime after 2015).

The study group consisted of officers with backgrounds in armoured infantry units, air defence units and an armed forces helicopter wing. One full-time and a number of part-time operations analysts from FOI supported the study.

This article does not describe the details of the study or the results, but instead presents the method used in order to carry out the initial phase of the study.

2. METHODOLOGY: MORPHOLOGICAL ANALYSIS

The general framework for the study employed the customary *systems analysis* (SA) cycle, with the following (iterative) steps:

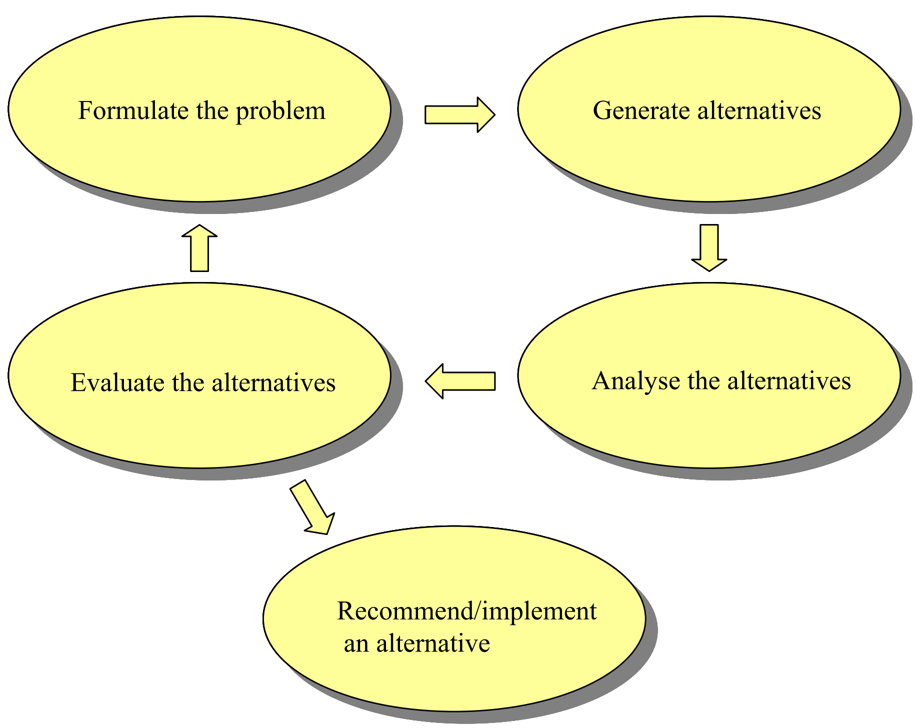

Figure 1: Systems analysis schema

Since Sweden has little experience with airborne combat units and close air support, the first three iterative steps -- beginning with "Formulate the Problem" -- were especially important. The study must not only structure the problem area in a coherent manner, but must also compile and structure as much knowledge as possible as to what an "airborne capacity" would mean for Sweden -- including how different factors could influence the development and configuration of such a capacity.
Because of the complexity of the study area, and in order to keep all options open, morphological analysis (MA) was employed as the initial method for structuring and analysing the problem complex. Morphological analysis was developed by Professor Fritz Zwicky – the Swiss-American astrophysicist and aerospace scientist based at the California Institute of Technology (CalTech) – as a general method for structuring and investigating the total set of relationships contained in multi-dimensional, non-quantifiable, problem complexes (Zwicky 1966, 1969; Fowles 1978)

Zwicky applied this method to such diverse tasks as the classification of astrophysical objects, the development of aircraft propulsion systems, and the legal aspects of space travel and colonisation. More recently, MA has been applied by a number of researchers in the U.S.A and Europe in the field of policy analysis and futures studies (Rhyne 1981, 1995; Reibniz 1987; Coyle 1994, 1995; Ritchey 1997; Jenkins 1997). At FOI, we have extended the method and developed computerised support for the entire analysis-synthesis cycle that MA involves (Ritchey 1998, Stenström & Ritchey 1999; Stenström& Ritchey, 2001; Eriksson, 2002).

The method begins by identifying and defining the most important dimensions of the problem complex to be investigated, and assigning each dimension a range of relevant ”values” or conditions. This is done mainly in natural language, although abstract labels and even quantities can be utilised to specify the set of elements defining the discrete domain of a variable.

Parameter A	Parameter B	Parameter C	Parameter D	Parameter E	Parameter F
Condition A1	Condition B1	Condition C1	Condition D1	Condition E1	Condition F1
Condition A2	Condition B2	Condition C2	Condition D2	Condition E2	Condition F2
Condition A3	Condition B3	Condition C3		Condition E3	Condition F3
Condition A4	Condition B4	Condition C4		Condition E4	Condition F4
Condition A5		Condition C5		Condition E5	
				Condition E6	

Figure 2: A 6-parameter morphological field. The darkened cells define one of 4800 possible (formal) configurations.

A morphological field is constructed by setting the parameters against each other in order to define an n-dimensional configuration space (see Figure 2). A particular "configuration" (the darkened cells in the matrix) within this space contains one ”value” from *each* of the parameters, and thus marks out a particular state of, or possible formal solution to, the problem complex.

The point is, to examine all of the configurations in the field, in order to establish which of them are possible, viable, practical, interesting, etc., and which are not. In doing this, we mark out in the field a relevant ”solution space". The solution space of a Zwickian morphological field consists of the subset of configurations which satisfy some criteria.

Obviously, in fields containing more than a handful of variables, it would be time-consuming -- if not practically impossible -- to examine all of the configurations involved. For instance, a 6-parameter field with 6 conditions under each parameter contains more than 46,000 possible configurations. Even this is a relatively small field compared to the ones we have been applying at FOI.

Thus the next step in the analysis-synthesis process is to examine the *internal relationships* between the field parameters and "reduce" the field by weeding out configurations which contain mutually contradictory conditions. In this way, we create a preliminary outcome or solution space within the morphological field without having first to consider all of the configurations as such.

Reducing the field is achieved by a process of cross-consistency assessment: all of the parameter values in the morphological field are compared with one another, pair-wise, in the manner of a cross-impact matrix (see Figure 2). As each pair of conditions is examined, a judgement is made as to whether – or to what extent – the pair can coexist, i.e. represent a consistent relationship. Note that there is no reference here to causality, but only to internal consistency.

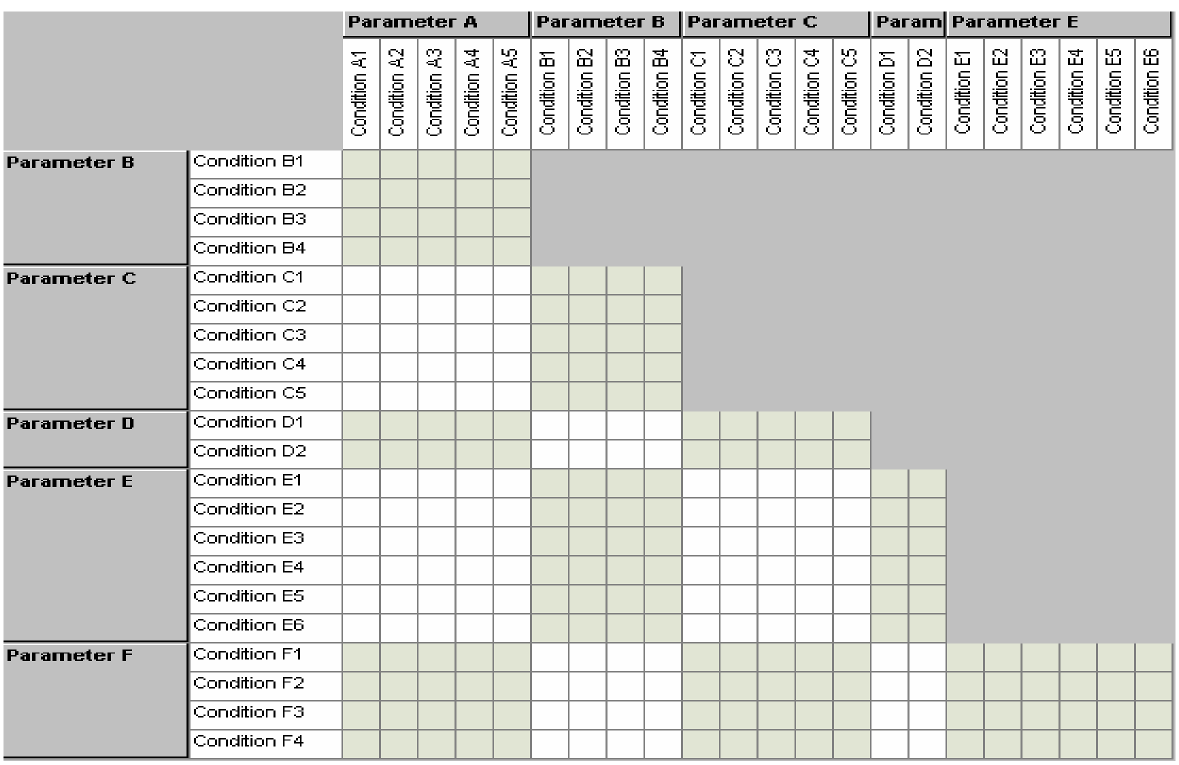

Figure 3: The cross-consistency matrix for morphological field in Figure 1.

There are two main types of inconsistencies involved here: purely logical contradictions (i.e. those based on the nature of the concepts involved), and empirical constraints (i.e. relationships judged be highly improbable or implausible on empirical grounds). It is also important to recognise normative constraints, e.g. relationships so politically or ethically distasteful that they can be ruled out. On the other hand, it is equally important not to allow such normative constrains to influence the evaluation process in a prejudicial manner. For this reason, we never allow normative judgements to constrain a morphological field *initially*: the initial reduction is based solely on logical and empirical judgements.

This technique of using pair-wise consistency assessments between conditions, in order to weed out internally inconsistent configurations, is made possible by a principle of dimensionally inherent in the construction of parameter spaces. While the number of configurations in such a space grows exponentially with each new parameter, the number of *pair-wise relationships between parameter conditions* grows in proportion to the triangular number series -- a quadratic polynomial.

Naturally, there are practical limits reached even with quadratic growth. The point, however, is that a morphological field involving as many as 100,000 formal configurations can require no more than few hundred pair-wise evaluations in order to create a solution space.

Once a solution space is created, the morphological field -- with suitable computer support* -- can be employed as a qualitative "input-output" model: one or more parameters can be used as drivers or inputs in order to examine what possible output options are available (see Figure 4, below). Such a "what-if" conceptual laboratory can be invaluable in examining and visualising complex scenario, policy or strategy spaces.

To sum up: The technique of matrixing parameters, in order to uncover the multiplicity of relationships associated with a problem complex, is nothing new. The virtually universal use of ”four-fold tables” and the study of typology construction as both a classification technique and for theory generation attests to this fact (Bailey 1994, Doty & Glick, 1994). However, Zwicky’s highly systematic approach to this method (and his use of far more dimensions than is practical in the case of traditional typologies) should not be underestimated. Used properly – and on the right types of problem complexes – the method is deceptively complex and rich.

The morphological approach has several advantages over less structured approaches. It seeks to be integrative and to help discover new relationships or configurations, which might be overlooked in other – less structured – methods. Importantly, it encourages the identification and investigation of boundary conditions, i.e. the limits and extremes of different parameters within the problem space.

It also has definite advantages for scientific communication and – notably – for group work. As a process, the method demands that parameters, conditions and the issues underlying these be clearly defined. Poorly defined parameters become immediately (and embarrassingly) evident when they are cross-referenced and assessed for internal consistency. Also, confusions between empirical and normative judgements are more easily avoided.

Morphological analysis demands, however, experienced process facilitation.

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* At FOI, we have developed computer support for the entire analysis-synthesis cycle, which MA involves. For further information, contact Tom Ritchey, FOI (ritchey@foi.se)

3. AIRBORNE CAPABILITY: PROBLEM FORMULATION

In order to formulate the problem complex, we created a preliminary morphological field describing what we believed an airborne unit should consist of, and what kind of tasks and environments this unit should be able to manage. As a starting point, we worked with the question of what types of missions the airborne unit should undertake and in what environments (column 1 in Figure 4, below). This resulted in several tactical scenarios (expressed in columns 1 & 2), which we then utilized as references in order to generate alternative forms and organisations for the airborne unit.

This morphological field helped us to understand where the major difficulties in the development of an airborne unit lay, where we lacked requisite knowledge and, importantly, what other systems of variables are dependent upon, and in their turn influence, how the airborne unit should be configured.

One of the main questions, which arose in this context, was which roles the *ground combat unit* could have in the missions executed by the airborne unit as a whole. As in the work with the airborne unit as a whole, we structured the ground combat unit on the basis of scenarios involving tasks and environments. These scenarios were formulated within the context of the main airborne unit matrix (Figure 4).

Task and milieu for Airborne Unit as whole	Task and milieu for Airborne Ground Combat Unit (AGCU)	Combat system for AGCU	Number of combat helecopters (75% availablility)	Unit's effective range	Command and control	Degree of collective training	Personnel and preparedness time	External support: time and degree of precision	External support: range
Engage mechanised brigade in open terrain	Retard armored tank units in open and covered and partially covered terrain	Light infantry	2 companies (16 helicopters)	Up to 100 km	Single overall organisational C&C unit	High	Full time employed 48 hours	Precision strikes within minutes	100 km
Engage II units in open and partially covered terrain	Engage advanced units in urban milieu	Combat system 2005-2010	1 company (8 helicoptors)	Up tp 150 km	No overall organisational C&C unit	Medium	Conscripts 10 dagar	Precision strikes within a few hours	150 km
Take and hold terrain in urban and partially covered milieu	Take bridgehead Partially covered and urban terrain	Combat system 2015-2020	None	Up to 200 km		Low	Contract 30 dagar	Saturation strikes within minutes	200 km
Engage advanced units in urban terrain	Relief/rescue operation			> 200 km				Saturation strikes within a few hours	> 200 km
Rescue and evacuate	Surface survailance - Target designation								
Supervise and support mission in open and partially open terrian									

Figure 4. Morphological field for Airborne Unit, with option space defined for the designated task: *Rescue and evacuate*.

Strike key function in urban environment	Troop & Weight	Protection	Transport & Distance	Helicopter alternatives
Combat system 2015-2020	750 st (battalion) 113 tons	Unit as a whole: personnel, equipmqnt, VMS	Equipment and personnel 20 km/h	100 km Maximum
Combat system 2010	600 st (battalion) 90 tons	Equipment: personnel, vehicles	All equipment 4 km/h	100 km Medium
Direct fire & light support	450 st (3 companies) 68 tons	Personal: personnel, equipment	Portion of equipment 2 km/h	100 km Minimum
Direct fire	300 st (2 companies) 45 tons		No vehicles 2 km/h	150 km Maximum
Only light armour piercing weapons	150 st (1 company) 22,5 tons			150 km Medium
				150 km Minimum
				20 km Maximum
				20 km Medium
				20 km Minimum

Figure 5. One of five scenario fields for the Airborne Ground Combat Unit. The field was used first to identify possible configurations for the task "Strike key function in urban environment", and then to determine weight requirements. The last parameter defines the array of helicopter alternatives.

In the ground combat unit matrix, we found that we needed to combine qualitative information (is this relevant; possible; advantageous?) and quantitative inputs, such as weight constraints, in order to create consistent alternatives. This meant that we needed to combine our morphological fields with optimization techniques, in order to find alternatives which maximise effect within the bounds of various constraints. In doing this, we created five morphological fields representing Airborne Ground Combat Unit (AGCU) scenarios. These were then used both to identify possible configurations, which were up to the task described by the scenario, and then to determine requirements based on weight, volume, range, etc. Figure 5 represents one of the five scenario fields for the AGCU.

One of our greatest uncertainties was the specifications concerning the transport helicopters. Our study was undertaken before any decision was made about helicopter procurement. Thus, we were in the unenviable position of having to "create" airborne combats units, to be lifted by helicopters, without knowing how many or what type of helicopters would be available. Helicopter specifications would stress such factors as the unit’s weight, volume and tactical behaviour, and thus strongly affect what tasks and under which conditions the unit would be able to operate.

We solved this problem by creating several helicopter profiles (last column in Figure 5), each defining a "tactical flight profile" and with three different ranges. The ranges were then combined with a mix of old helicopter types still in use in Sweden, and a new generic helicopter type. In this way, we created “profile packages” for the helicopters, each associated with constraints concerning fuel consumption, tactical behaviour, range and weight.

The next step was to do some war gaming on the basis of the initial study using morphological analysis. We have found that the morphological fields developed for the study gave us almost ready-made inputs for war gaming. The gaming, in turn, gave us valuable feedback for refining and further developing the morphological fields. We found this combination of top-down and bottom-up studies (i.e. the process of analysis-synthesis cycles) provided us both with a reciprocal check on results and means of compiling are structured database.

C^2 CAPABILITY

A preliminary C2 evaluation was later appended to the study. It was limited to identifying the main relevant parameters for a C2 capability. The fifteen parameters initially identified were:

1. Command activity
2. Command level
3. Command process
4. Command system
5. Command and leadership style
6. Decision making
7. Control method
8. Organisational structure
9. Staff organisation principle
10. Number of hierarchical levels
11. Staff size
12. Number of “direct subordinate officers”
13. Personnel quality
14. Information system properties
15. Interoperability

One of the morphological fields developed on the basis of these parameters is shown in Figure 6 (below). It has not yet been internally assessed.

Command level	Command process	Command and leadership style	Principal control method	Organisational structure (Methods and processes)	Principal staff organisational grouping
Military strategic	Planering command	Personal Authoritarian Intuitive	"Command" (Relatively detailed control)	Centralised Distributed Mobil	Functional grouping
Operational	Operations command	Non-personal Authoritarian Intuitive	Mixed	Centralised Concentrated Mobil	Process grouping
Tactical	Evaluation/ assessment command	Personal Non-authoritarian Intuitive	"Task" (Little direct control)	Centralised Distributed Fixed	Force grouping
Combat technical		Non-personal Non-authoritarian Intuitive		Centralised Concentrated Fixed	
		Personal Authoritarian Analytic		Decentralised Distributed Mobil	
		Non-personal Authoritarian Analytic		Decentralised Concentrated Mobil	
		Personal Non-authoritarian Analytic		Decentralised Distributed Fixed	
		Non-personal Non-authoritarian Analytic		Decentralised Concentrated Fixed	

Figure 6. One of the preliminary morphological fields developed to investigate C^2 capabilities.

Conclusions

In the initial phase of the work to develop an Airborne Capability, we created:

- One morphological field describing the resources and structure of the airborne unit, which develops airborne capacity
- Five scenario specific fields that describes the resources for the ground combat unit, which is a part of the airborne unit
- One field which shows the role for the ground combat unit in the airborne unit
- One field which describes external fire support for the airborne unit
- One preliminary field describing six C^2 parameters

Morphological analysis not only helped us to structure the problem complex and to build alternatives for the airborne units; it also aided us in ascertaining where knowledge was lacking. The morphological fields became databases where such variables as weight constraints, range and flight profiles could be related to different scenarios and alternatives. To be able to develop the alternatives for the ground combat unit, we had to combine qualitative analysis of the parameter conditions with optimisation techniques. The creation of these fields also turned out to be an excellent way of preparing war games.

The method has also helped us to work with uncertainties, since we were able to define and examine a large solution space, which was gradually reduced during the evaluation process. The result – besides the knowledge that has been generated and documented in the process – is a laboratory in which one can formulate internally consistent alternative structures for the airborne units.

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